Toxic Metals-pH Impact
On Riparian Plant Community Structure
At Grant-Kohrs Ranch

prepared for

Grant-Kohrs Ranch National

Historic Site

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By

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Executive Summary

Canopy cover of all vascular plants was determined in thirty megaplots within the Grant-Kohrs Ranch riparian zone during mid-summer 2001. These megaplots were the same locations used by Moore for measuring metal contamination of soils, Gannon for measuring soil respiration, and Kapustka for determining soil phytotoxicity and field biomass production. The objective of measuring canopy cover at these megaplot locations was to determine if there was a relationship between plant community structure and metal contamination. Multivariate ordination techniques were used to graphically and numerically show the similarity in species composition between megaplots, and the correspondences of changes in community structure with changes in pH adjusted metal loading of the soil.

Megaplots with the highest pH adjusted metals have similar species composition and differ as a group from megaplots with low and intermediate metal loading. The changes in species composition were strongly correlated with changes in pH adjusted metal loads of the soil. A rotated joint plot indicated that pH adjusted metals explained 63.5% of the variance in community structure along the primary axis of an ordination by non-metric multidimensional scaling. A null hypothesis of no relationship between pH adjusted metals and plant community structure was rejected as a Monte Carlo test of eigenvalues calculated for a canonical correspondence analysis had p=.02 for the first axis. This canonical correspondence analysis provides confirmation of the impact of metals on community composition.

The abundance of three species known to be metal tolerant was positively correlated with increasing pH adjusted metal contamination of the soil. Tufted hairgrass, redtop bentgrass, and Booth willow canopy cover increased as metal loading became more severe. Conversely other species declined in abundance with increasing pH adjusted metal contamination of the soil.

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1) Introduction

a) Setting

Grant-Kohrs Ranch National Historic Site is in Deer Lodge, Montana. This historic cattle ranch consists of 1,500 acres of irrigated pastures/hayfield, upland range, and riparian habitat. The livestock are excluded by fencing from 127 acres of the riparian zone. The Clark Fork River has deposited mining and smelting tailings throughout the riparian zone. This study is based on sampling done within the riparian zone.

b) Objective

Determine if heavy metal contaminated sediments in the riparian zone of the Grant-Kohrs Ranch are altering plant community composition.

2) Materials and Methods

a) Sampling design

Selection of megaplot locations in the riparian zone is described in Moore and Woessner (2001). The design and layout of the megaplots is reported in Kapustka (2001).

Circular plots $50m^2$ were centered on each of the 30 previously chosen megaplots. Vegetation data was collected following the standardized ocular macroplot method described in Hann and Jensen (1987). Plot size and methodology correspond to the procedures used by Hansen et al. (1995) for characterizing riparian communities. For each plant species Daubenmire cover class (T, P, 1, 2, …..9,F) and mean height was recorded. The sampling was done from July 25 through August 14, 2001.

b) Soil chemistry variables

Moore and Woessner (2001) collected and analyzed soil sample from the megaplots. They measured organic carbon, pH, arsenic, cadmium, copper, lead and zinc. The metals were determined as total digestible metals. Kapustka (2001) demonstrated that a pH adjusted summation of arsenic, copper, and zinc concentrations was the most useful measure for relating metal availability and phytotoxicity. The Kapustka (2001) pH adjusted metal loading is referred to as the K index in the graphs and tables of this report on plant community impacts.

c) Data analysis

Taxa with constancy less than five percent (observed in only one megaplot) were excluded from the community data set. A multivariate outlier analysis was then conducted on the community composition data for the megaplots. Sørensen distance was used for screening the plot data prior to non-metric multidimensional scaling, and the Chi-squared distance measure prior to canonical correspondence analysis. Megaplots with average distance to other megaplots in species space > 2.0 standard deviations from the grand mean of distances were considered outliers. Megaplots with high organic carbon or pH also were excluded so that treatment of the community data would be consistent with the ep & t (Kapustka 2001) analysis of phytotoxicity and field biomass production.

A canonical correspondence analysis (CCA) (Jongman et al. 1995) was conducted to test the null hypothesis of no relationship between pH adjusted metals and plant community structure. The second matrix included organic carbon as well as K index. The eigenvalues for the axis of the constrained ordination using the real data structure were compared to a Monte Carlo simulation based on randomizing the megaplots in the first matrix (canopy cover) relative to the megaplot soil variables in the second matrix. The 99 randomizations provided a resolution of 0.01 for the resulting estimate of the probability of Type I error.

Non-metric multidimensional scaling (NMS) was used to show the compositional similarity of the megaplot communities (Legendre and Legendre 1998, Jongman et al. 1995). A non-metric multidimensional scaling joint plot was developed to show the relationship of community structure with the two soil variables (organic carbon and pH adjusted metals [K index]). The non-metric multidimensional scaling solution was rotated to maximize the correlation of pH adjusted metals with the first axis of the ordination. After rotation the percent of variation explained along the primary axis was estimated by calculating the coefficient of determination between the Euclidean distances in the ordination space and the Sørensen distances in the original space (McCune and Mefford 1999).

These multivariate analyses were executed using PCOrd Version 4.15 (McCune and Mefford 1999).

3) Results

a) Outlier analysis

Sixty-eight taxa were present in two or more megaplots. Four megaplots (24, 56, 62, 79) were dropped because of high organic carbon content (≥7.6%) or high pH (8.25); this made analysis of the species composition consistent with the Kapustka (2001) treatment of the phytotoxicity data. Three megaplots were dropped (18, 65, 71) because they were structural outliers (standard deviation > 2.0) based on calculation of Sørensen and/or Chi-squared distance measurements. Megaplot 71 was a slicken with only two species, tufted hairgrass and sandbar willow, at very low cover values. The remaining twenty-three megaplots were subjected to non-metric multidimensional scaling and canonical correspondence analysis.

b) Canonical correspondence analysis

The first two axes of the canonical correspondence analysis represented 13.6% of the variation in species composition. The eigenvalues for these two axes were stronger than expected by chance (Table 1). The Monte Carlo test of eigenvalues has p=.02 for the first axis. Because the first axis was almost purely related to K index (Figure 1) and the eigenvalue for the first axis was significant, the null hypothesis of no relationship between pH adjusted metals and plant community structure is rejected.

Table 1. Monte Carlo Test Results – Eigenvalues Calculated By Canonical Correspondence Analysis

	Real data	Randomized data Monte Carlo test, 99 runs			
Axis	Eigenvalue	Mean	Minimum	Maximum	p
1	0.246	0.174	0.102	0.251	0.02
2	0.201	0.117	0.067	0.233	0.02
3	0.450	0.475	0.401	0.500	0.86

p = proportion of randomized runs with eigenvalue greater than or equal to the observed eigenvalue; i.e., p = (1 + no. permutations >= observed)/(1 + no. permutations)

The pH adjusted metal loading (K index) had an inter-set correlation of .848 with the first canonical axis (Figure 1). The organic carbon inter-set correlation with the first axis is only .204.

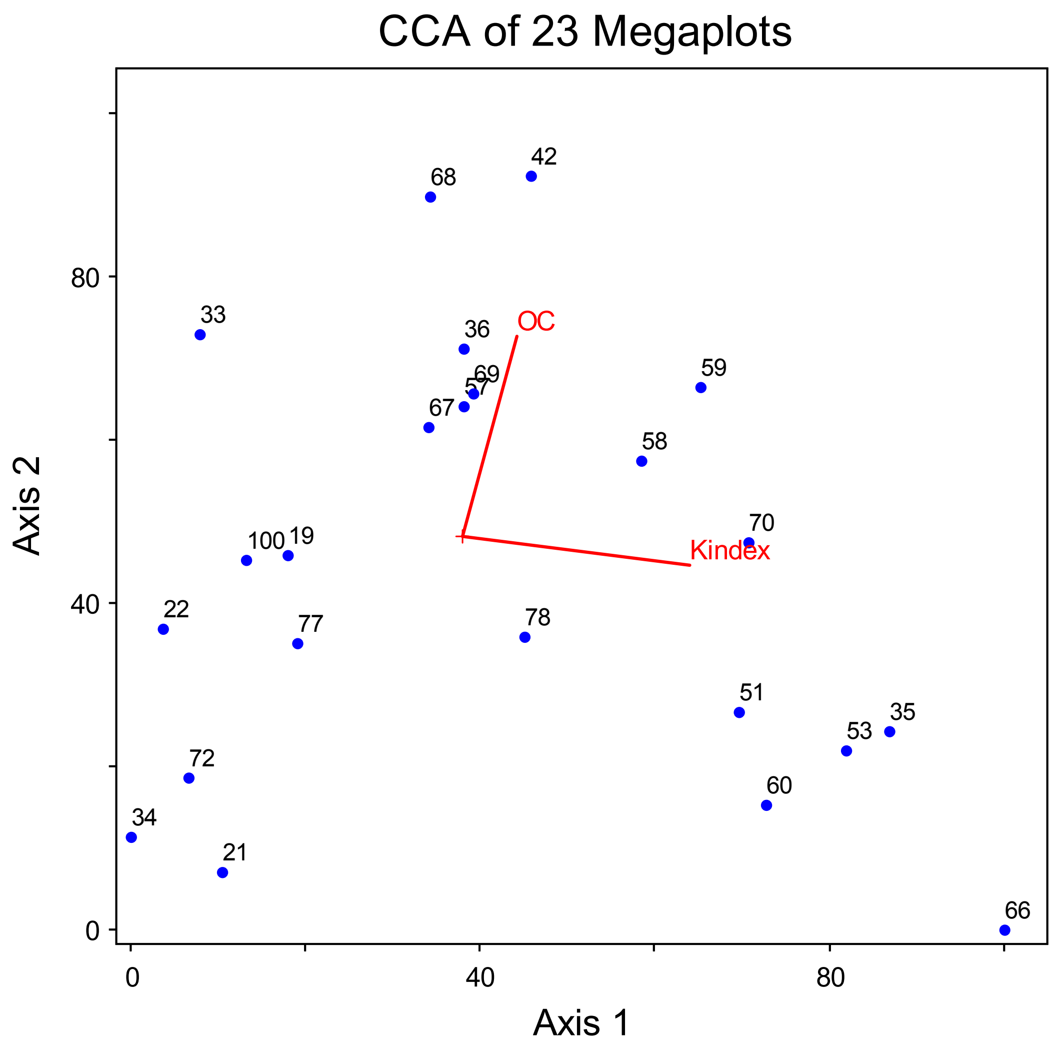

Figure 1. Joint plot showing relationship of soil variables to the axes of the canonical correspondence analysis.

Megaplots with the highest pH adjusted metals (larger dots) are positioned in the lower right hand corner of the ordination diagram (Figure 2). The simple linear correlation between metal loading, K index on vertical axis of the lower graph, and plot score along the first axis is .992. This correlation is stronger than the corresponding correlation of .542 for the NMS ordination (Figure 4) because CCA constrains the ordination with the environmental variables.

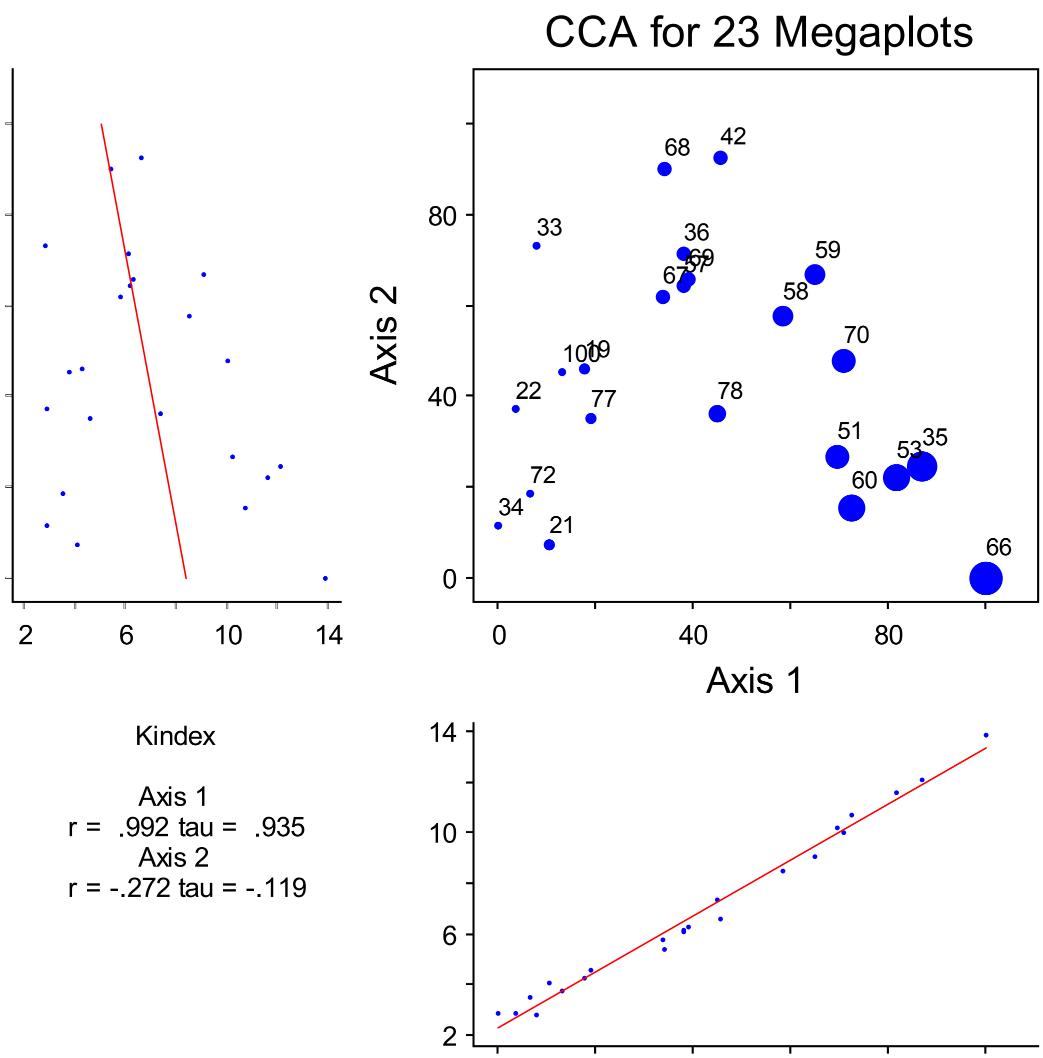

Figure 2. Overlay of metal loading (K index) with axes of the canonical correspondence analysis.

c) Non-metric multidimensional scaling with rotation

A two dimensional NMS solution provided the optimal solution for the species canopy cover data (Stress = 16.5). A joint plot with the soil variables, K index and organic carbon, was constructed (Figure 3). The megaplot hypercloud was then rotated to obtain the maximum correlation of K index with the primary ordination axis. K index correlation with the first axis reached .542 (Figure 4), while the organic carbon correlation with the first axis approached zero (-.048). These correlations and the joint plot show that the community variation related to organic carbon was essentially independent of and subordinate to the variation related to K index.

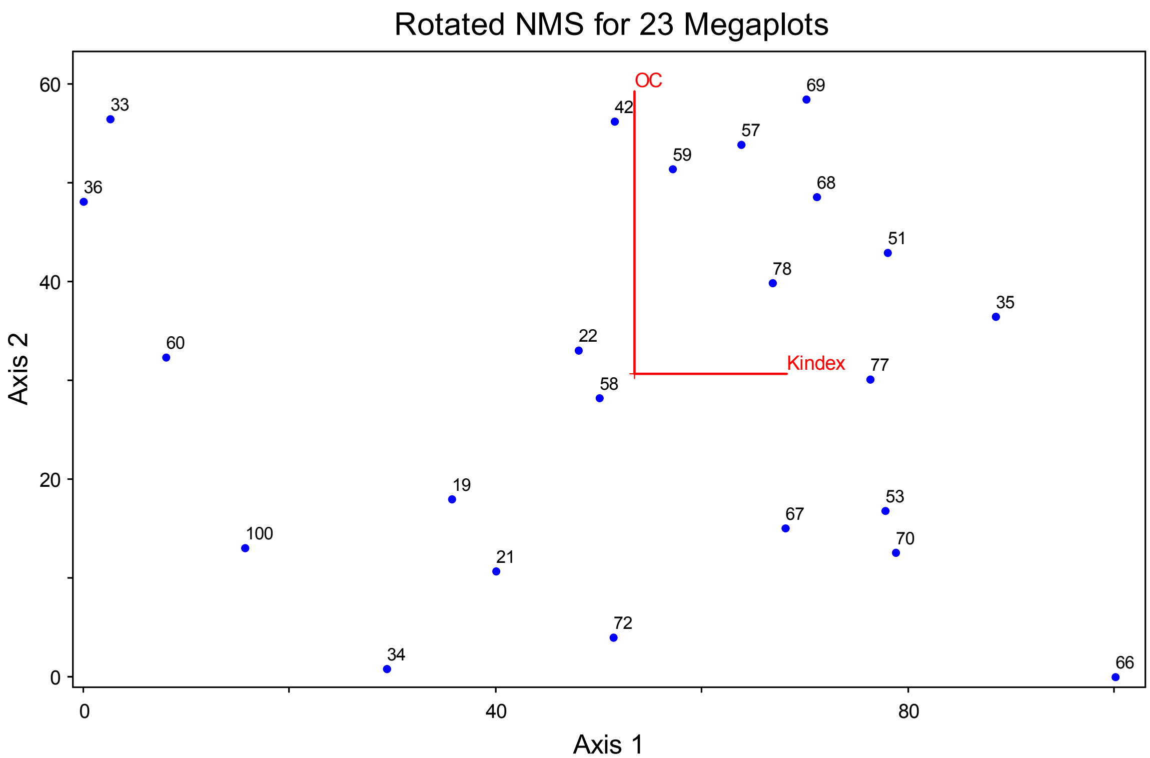

Figure 3. Rotated joint plot of pH adjusted metal loads (K index) within plant community megaplots (non-metric multidimensional scaling).

The rotated NMS solution represented 63.5% of the variance in community structure along the primary axis and 14.7% of the variance on the second axis for a total of 78% of variances represented by the first two axes (Table 2).

Table 2. Coefficients of Determination (R Squared) for the Correlation Between Ordination Distances And Distances In the Original N-dimensional Space		
Axis	Increment	Cumulative
1	.635	.635
2	.147	.782

Except for number 60, the megaplots with the highest pH adjusted metal loading (K index) have similar structure and are grouped on the extreme right side of the primary axis of the ordination (Figure 4). The size of the megaplot dot indicates the relative pH adjusted metal load.

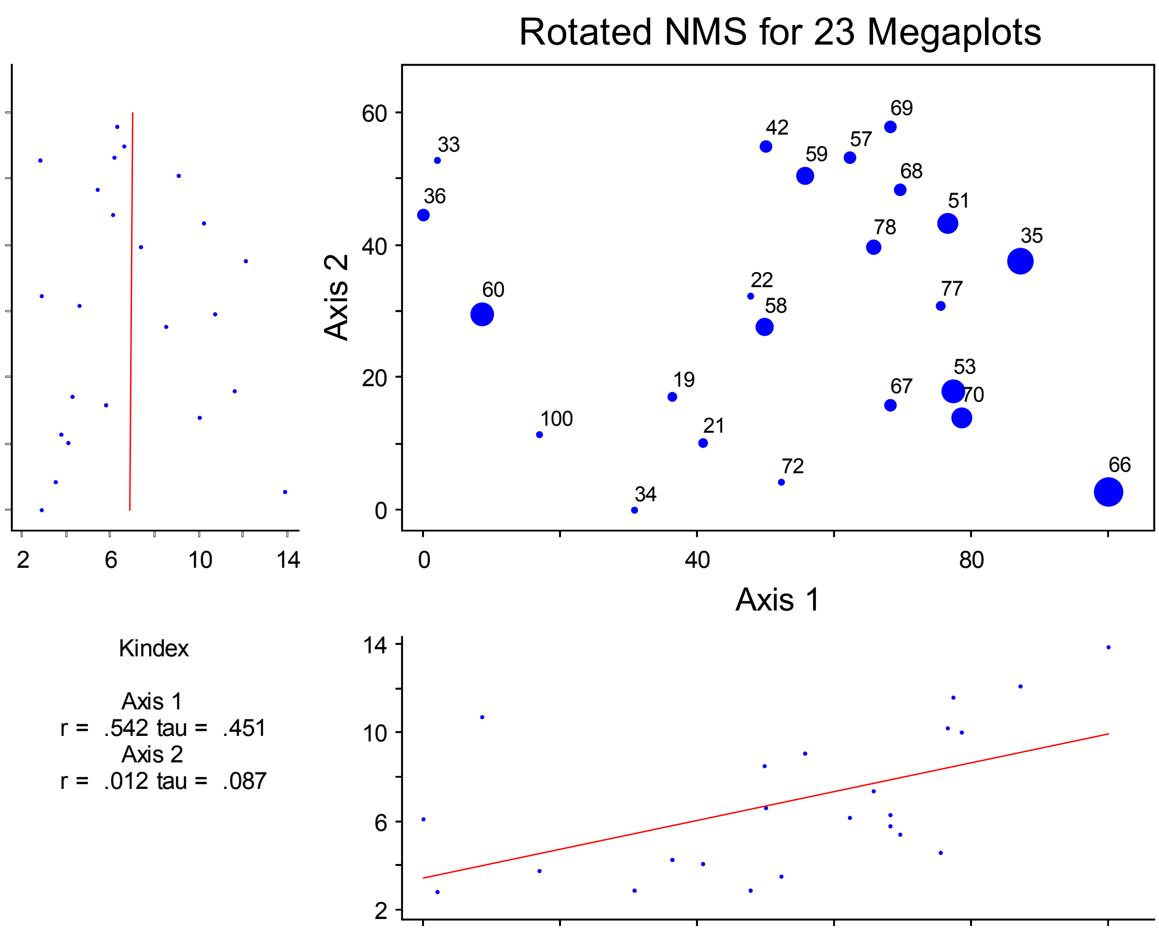

Figure 4. Correlation and magnitude of metal loading (K index) along axes of the non-metric multidimensional scaling ordination.

The three species whose abundance shows the highest positive correlation with the first axis are believed to be metal tolerant (Massey 1998). They are tufted hairgrass (Deschampsia cespitosa), redtop bentgrass (Agrostis stolonifera), and Booth willow (Salix boothii) (Table 3).

Table 3. Significant Correlations of Species Canopy Cover With First Ordination Axis After Rotation			
Common Name	**Acronym**	**R**	**p**
Tufted hairgrass	DESCES	.684	<.01
Redtop bentgrass	AGRSTO	.423	<.05
Booth willow	SALBOO	.409	<.05
Woundwort	STAPAL	.404	<.05
Hoary cress	CARDRA	-.536	<.01
Kentucky bluegrass	POAPRA	-.541	<.01
Quackgrass	AGRREP	-.653	<.01
Smooth brome	BROINE	-.868	<.01

Five species (Stachys palustris, Cardaria draba, Poa pratensis, Agropyron repens, Bromus inermis) had significant negative correlation with the first axis. These species are sensitive to the presence of metals.

An overlay of tufted hairgrass abundance (larger dots indicate greater canopy cover) along the first axis illustrates its strong positive association with the megaplots having highest pH adjusted metal loading (Figure 5).

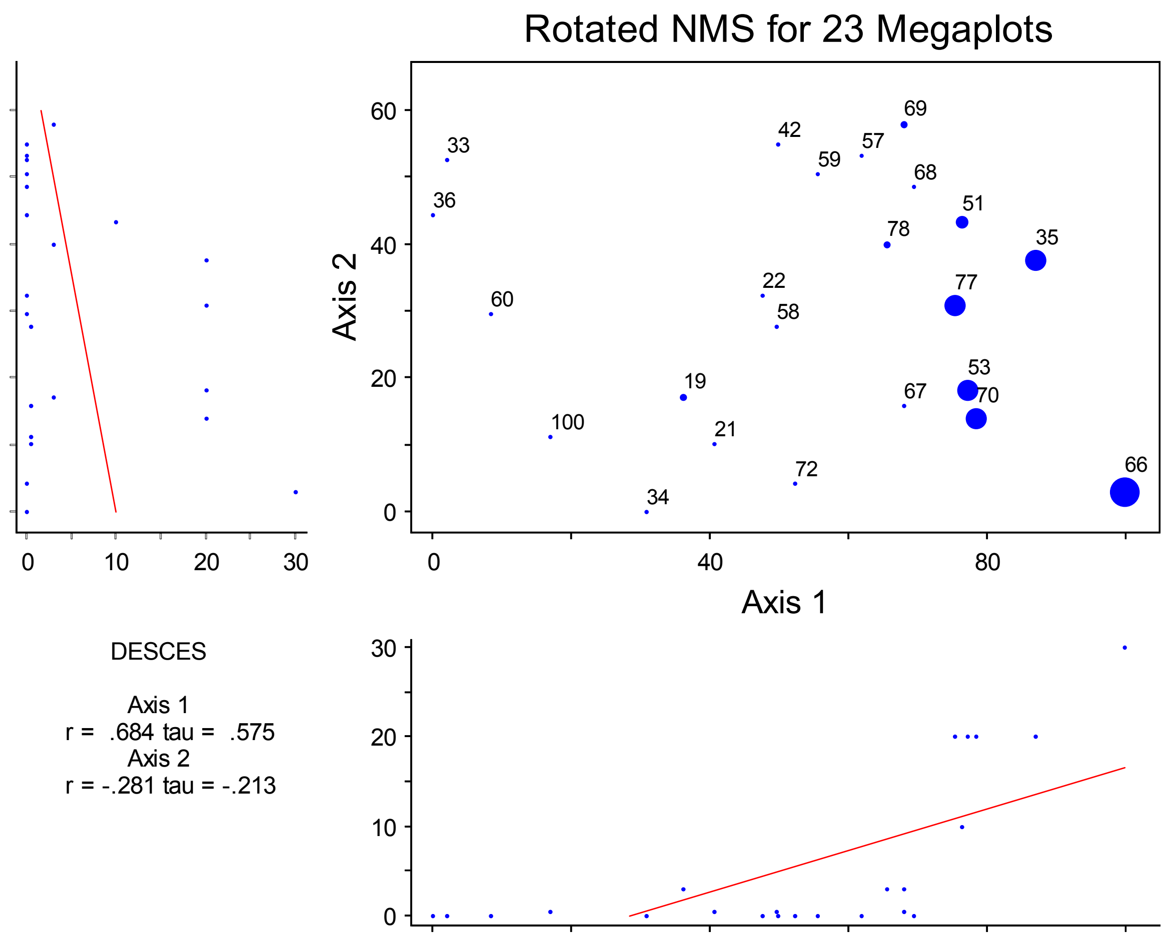

Figure 5. Overlay of tufted hairgrass (DESCES) canopy cover along the axes of the non-metric multidimensional scaling ordination.

Redtop bentgrass and Booth willow show peak metal tolerance at intermediate-high pH adjusted metal loading, then abundance declines in the megaplots with the highest pH adjusted metal loading (see overlay graphs Figures 6 & 7 in Appendix 1).

4) Conclusions

Concentrations of metals, adjusted for pH, are strongly related to the major gradient in plant community composition in the Grant-Kohrs Ranch riparian zone. A significant proportion of the variance in community structure can be explained by metal contamination. The relative abundance of several plant species known to be metal tolerant is increased in response to the metal loading. All three of the species most strongly and positively related to the metals gradient are reported to be tolerant of metal contamination. The most plausible explanation for the observed patterns is that metals have altered the plant communities of the riparian zone of the Grant-Kohrs Ranch by favoring certain species at the expense of others.

5) References Cited

Hann, W.J. and M.E. Jensen. 1987. Chapter 4: ECODATA sampling methods. *Ecosystem Classification Handbook.* FSH 12/87 R-1. Northern Regional Office: USDA Forest Service.

Hansen, Paul L., Robert D. Pfister, Keith Boggs, Bradley J. Cook, John Joy, and Dan K. Hinckley. 1995. *Classification and Management of Montana's Riparian and Wetland Sites.* Miscellaneous Publication No. 54. School of Forestry, University of Montana, Missoula, MT.

Jongman, R.H.G., C.J.F. Ter Braak, and O.F.R. Van Tongeren. 1995. *Data Analysis in Community and Landscape Ecology*. Cambridge University Press, Cambridge, U.K.

Kapustka, L. 2001. Phytotoxicity Tests on soils from the Grant-Kohrs Ranch National Historic Site, Deer Lodge, Montana. ecological planning & toxicology, Inc. Corvallis, OR.

Legendre, P. and L. Legendre. 1998. *Numerical Ecology, Second English Edition*. Elsevier Science, Netherlands.

Massey, J.G. 1998. Ordination analysis regarding the influence of trace element enhancement on the distribution of riparian plants in the Upper Clark Fork River Operable Unit. University of Montana, School of Forestry, Missoula, Montana. June 29, 1998.

McCune, B. and M.J. Mefford. 1999. *PC-ORD: Multivariate Analysis of Ecological Data. Version 4*. MjM Software Design, Gleneden Beach, OR.

Moore, J.N., B. Swanson, and C. Wheeler. 2001. Geochemistry and Fluvial Geomorphology of Grant-Kohrs Ranch National Historical Park, A Draft Report to the Grant-Kohrs Ranch National Historical Park, October 24, 2001

6) Appendices

Appendix 1. Overlay graphs for abundance of redtop bentgrass and Booth willow.

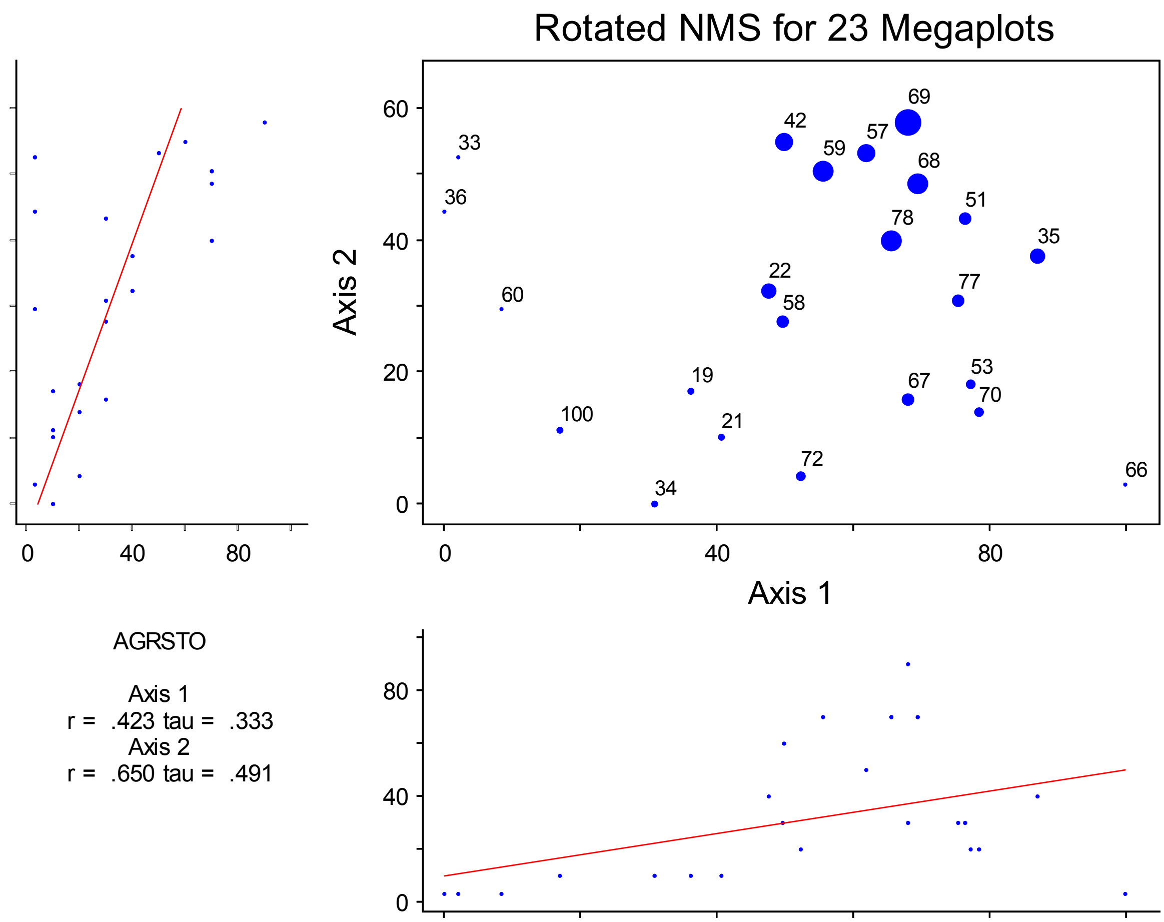

Figure 6. Overlay of redtop bentgrass (AGRSTO) canopy cover along the axes of the non-metric multidimensional scaling ordination.

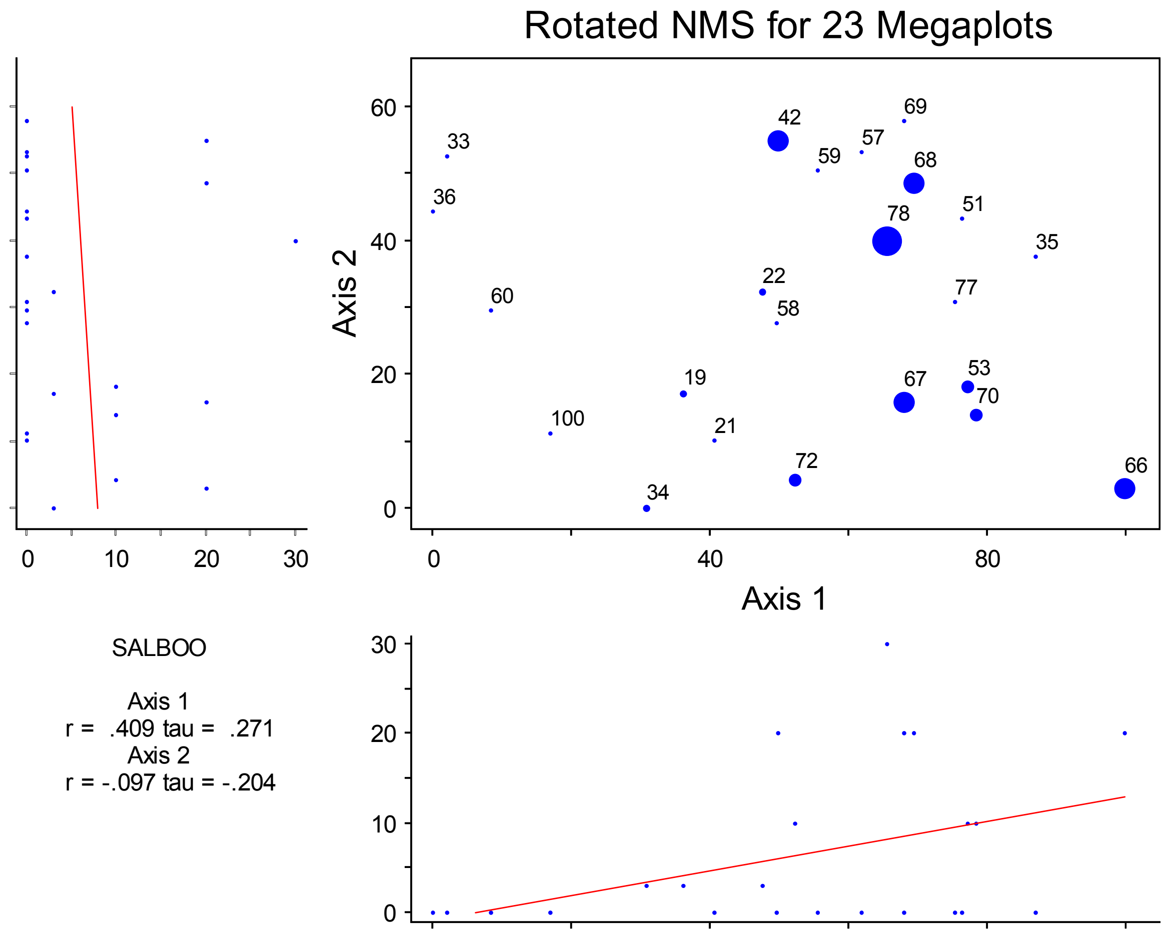

Figure 7. Overlay of Booth willow (SALBOO) canopy cover along the axes of the non-metric multidimensional scaling ordination.